Helping to keep the lights on,
businesses running
and communities strong®

Geomagnetically Induced Current (GIC)

What ATC is doing about it

August 28, 2013

Summary

- Industry Participation
  - NERC GMD TF 1
  - NERC GMD TF 2
- Internal Program
  - Working Group
  - Monitoring
  - Modeling
  - Mitigation

ATC's Industry Participation

NERC GMD TF– February, 2011 though February 2012

- Task force met four times in 2011
- Conference calls:
  - Preparation for NERC GMD Assessment Report
  - Review of Report
- NERC Interim Assessment February 2012 Findings
  - Voltage Collapse for Severe Storm
  - Need to Make progress in the following areas:
    - Operational Procedures
    - Monitoring
    - Modeling
    - Mitigation

NERC GMD TF 2

– Reformed in August 2012

1. Four teams
    - Analyzing the System
    - Transformers and Equipment
    - Storm modeling
    - Operating Practices
2. Face to face meetings in February and July 2013
    - Team Reports
    - Industry experience
    - Team Strategies

ATC’s Internal Program—Working Group

Formed in March 2012

- Purpose to implement recommendations of NERC GMD Report

– ATC Working Group

- Charter
- Executive sponsorship
- Cross functional team
  - Planning, Asset Management, System Protection, Transformer SME, Operations, Regulatory
- Meets regularly
- Attends related webinars
- Representation on NERC GMD TF2

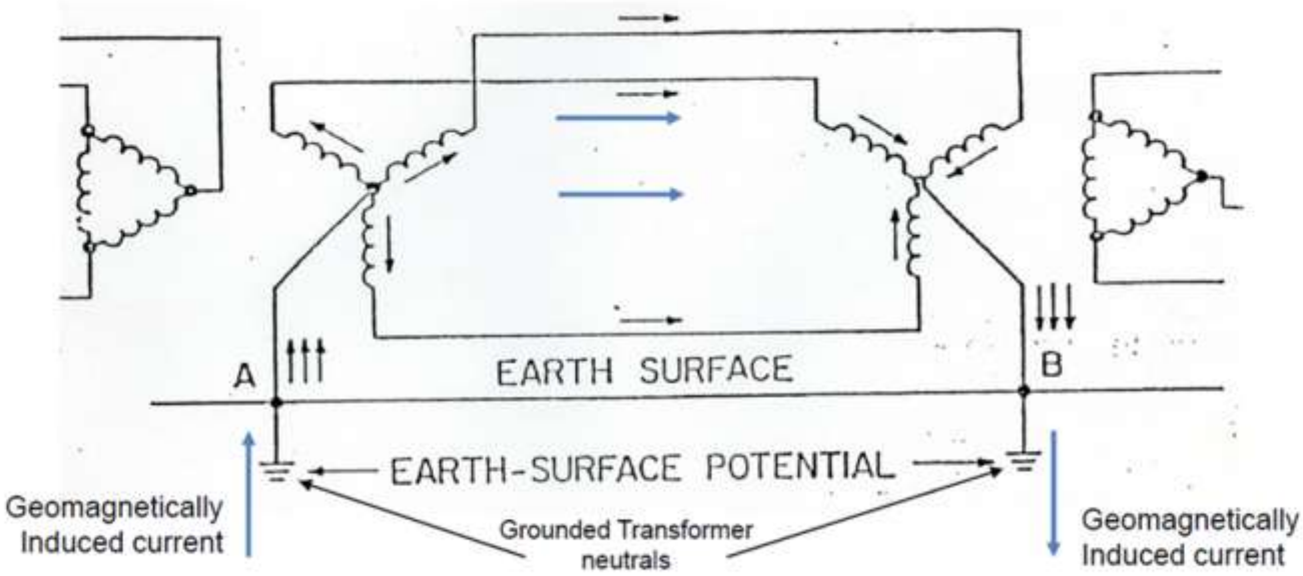
ATC's Internal Program--Monitoring

- GIC Monitoring – measure the issue
  - 22 current monitors installed at this time
- GIC Effects
  - Even Harmonics Measurement (an indication of transformer saturation from DC current bias)
  - MVAR Loading for indication of transformer saturation

Monitoring—Circuit Model

Geo-magnetically Induced Current Example

- In this standard transmission line setup GICs flow from the earth into the grounded neutral of a three phase wye connected transformer, where it divides evenly in each phase of the transformer. The GIC then proceeds into transmission lines and flows to other transformers, returning from them to earth.



Earth surface potential is a function of storm intensity and earth conductivity.

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GIC Monitoring

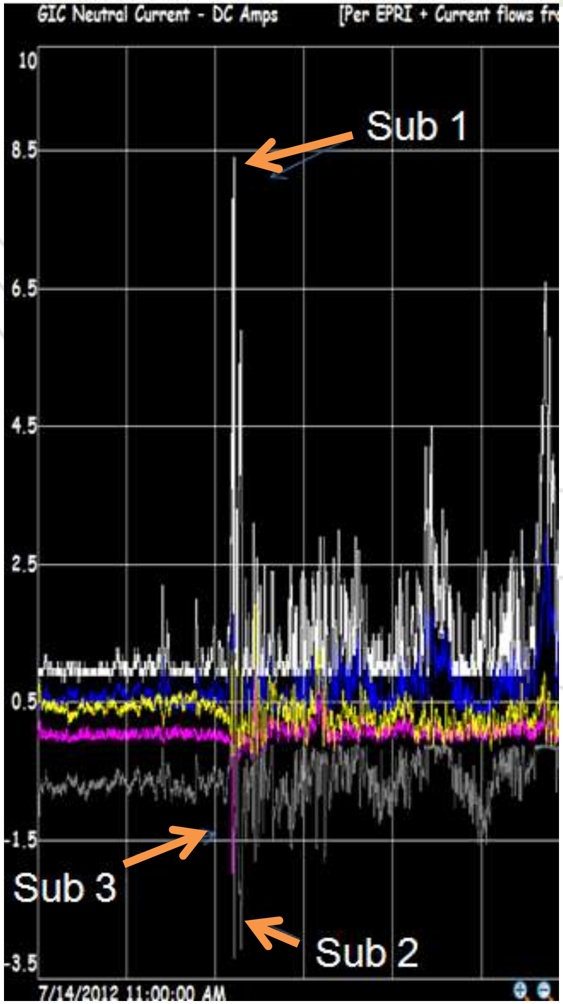
- ATC Doubled GIC Monitor Platform to 22 in 2012
- ATC In-house Design
  - Standard Parts
    - Hall Effect CT
    - Signal Processing
    - Power supply
    - Circuit proving
  - Custom Design and testing
  - DC current only
  - Feeds EMS
- Industry Offerings Now Available

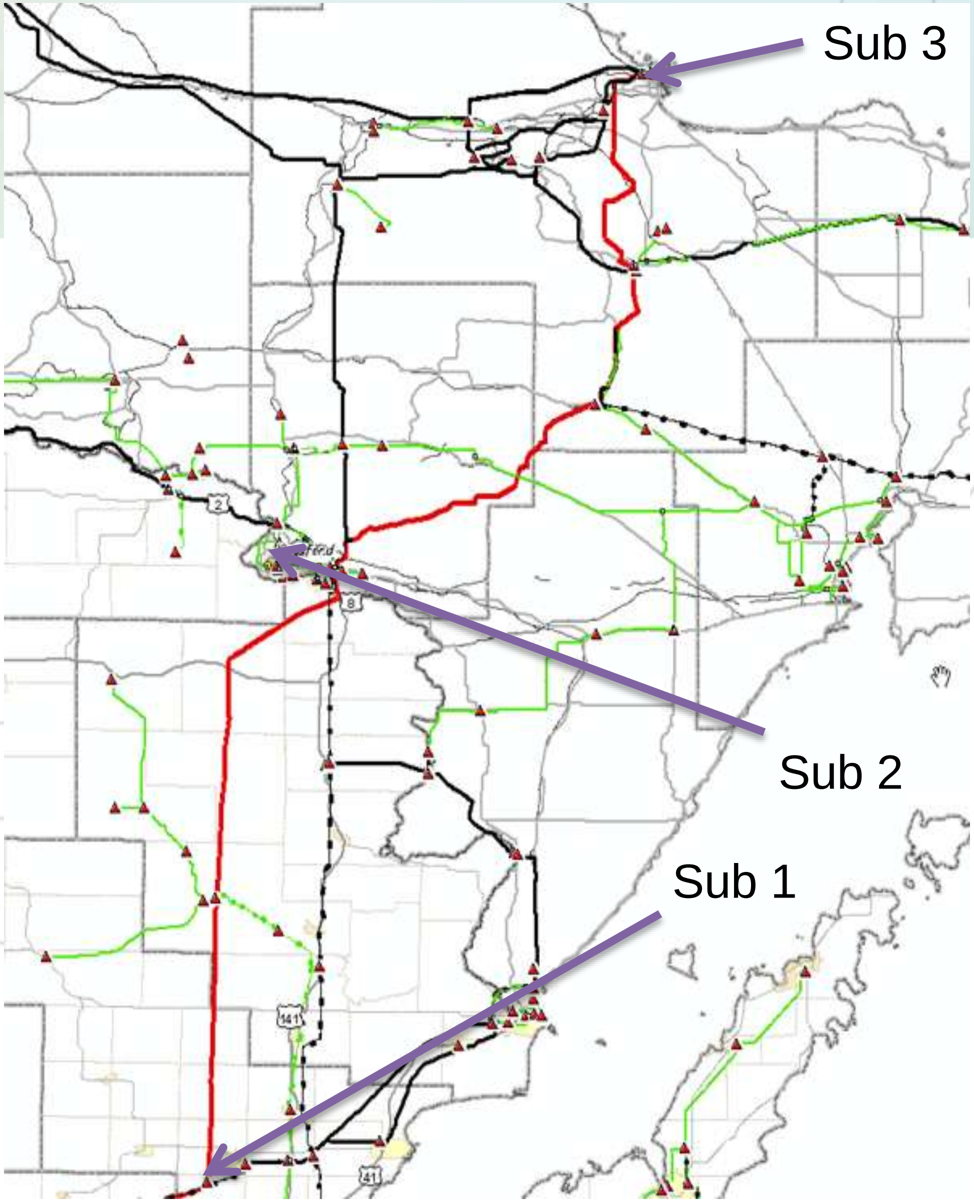
GIC Monitor Installation

CT box with
N-G feed
through

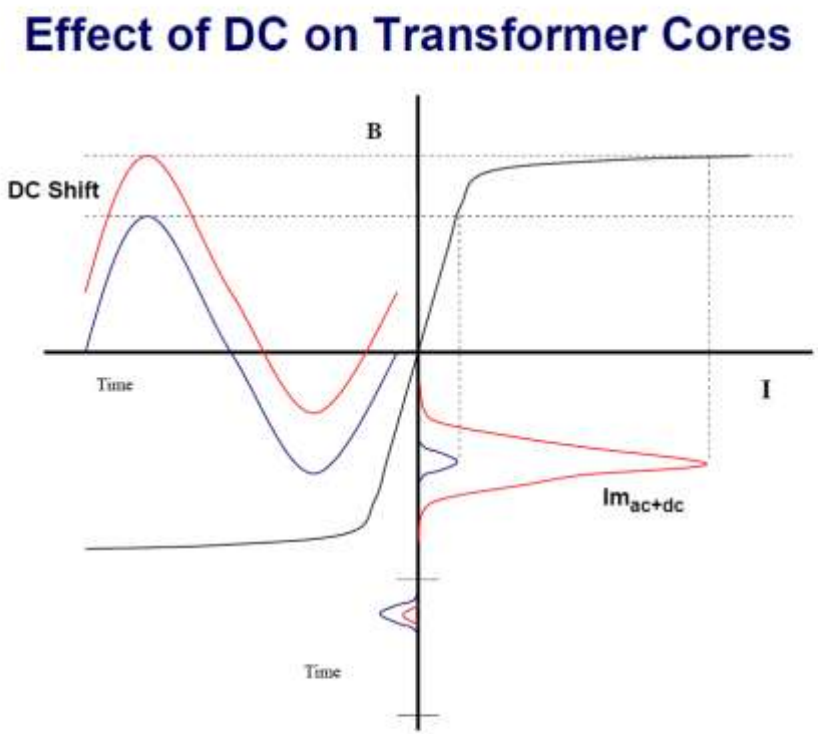
Monitoring GIC

Circuit Actual Example





Monitoring—Saturation of Transformer



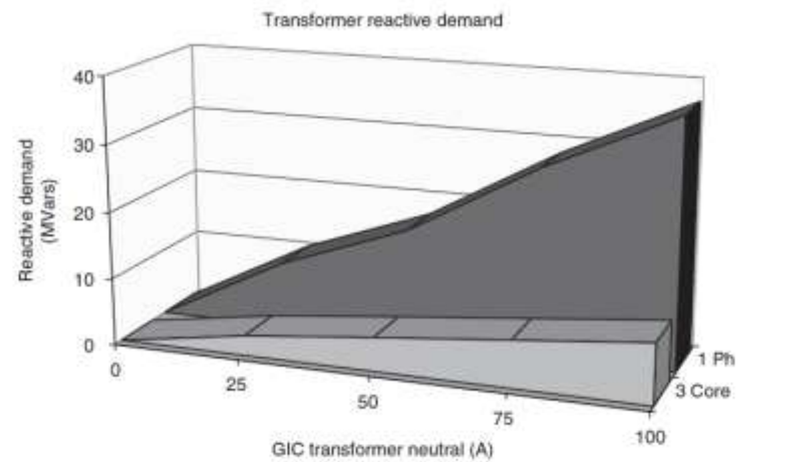
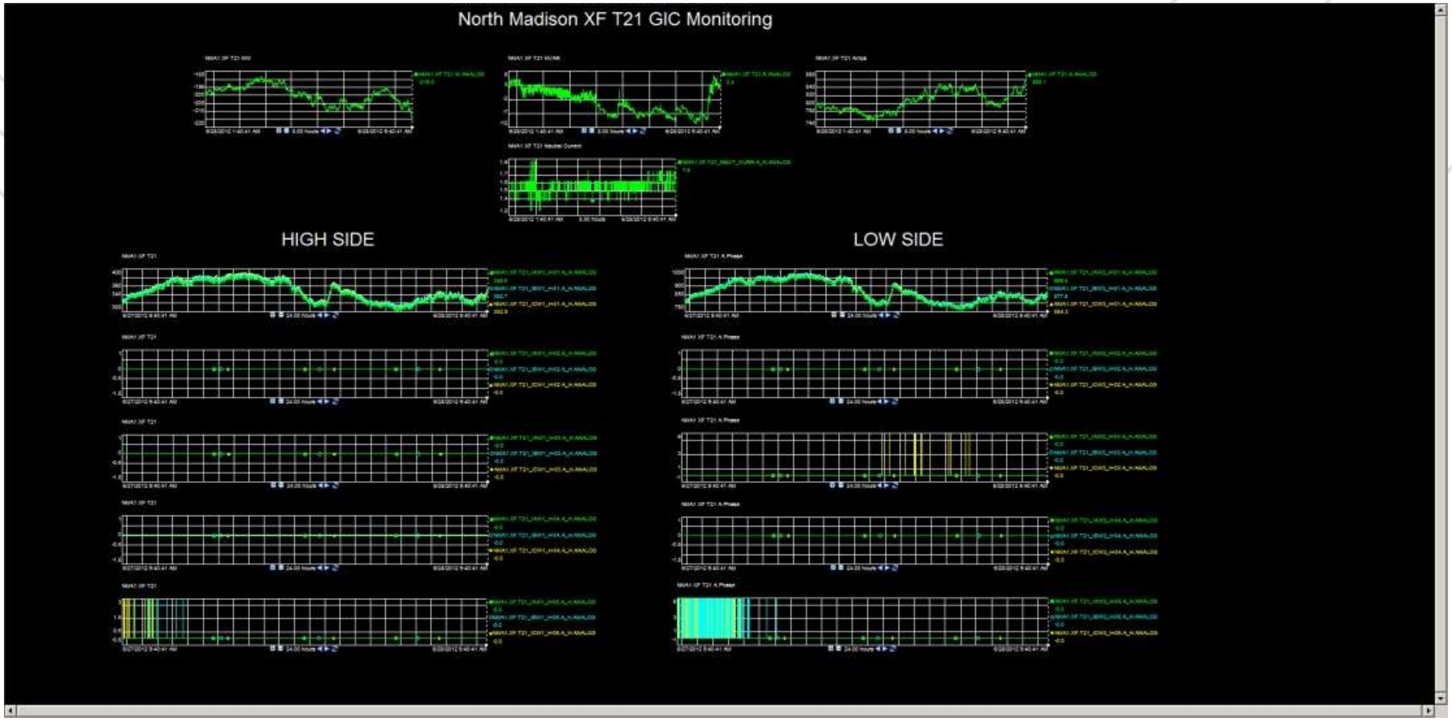


FIGURE 16.4 The exciting current drawn by half-cycle saturation conditions shown in Fig. 16.3 produces a reactive power loss in the transformer as shown in the top plot. This reactive loss varies with GIC flow as shown. This was measured from field tests of a three-phase bank of single-phase 500/230 kV transformers. Also shown in the bottom curve is measured reactive demand vs. GIC from a 230/115 kV three-phase three-legged core-form transformer. Transformer core design is a significant factor in estimating GIC reactive power impact.

Monitoring the Effects of GIC on Transformers

- 1^{st} – 5^{th} Harmonics and neutral current using the existing transformer differential relays
- Use “Even” Harmonics to determine transformer **partial** saturation
- Use transformer magnetizing (excitation) MVAR load for indication of **full** saturation



Monitoring EMS and Alarms

- 2nd Harmonics to indicate **initial** saturation
- Excitation current to indicate **advanced** saturation
- Calculated estimate of MVAR consumed in the transformer
- 20 minute history for trending
- Existing bus voltage
- **46** of **62** transformers will have harmonics measurements using SEL relays

ATC Operational Procedure (Real-time)

- Preemptive measures
- Add Capacitive VARS at substation when 2nd harmonics are present or Transformer Excitation MVAR Load
- Monitor bus voltage for exact amount of capacitance to add
- Switch out reactors in the area
- Unload saturated transformers (that exhibit “Even” harmonics and/or MVAR load
- Notify Maintenance if you have a saturated transformer (next day for follow-up testing)

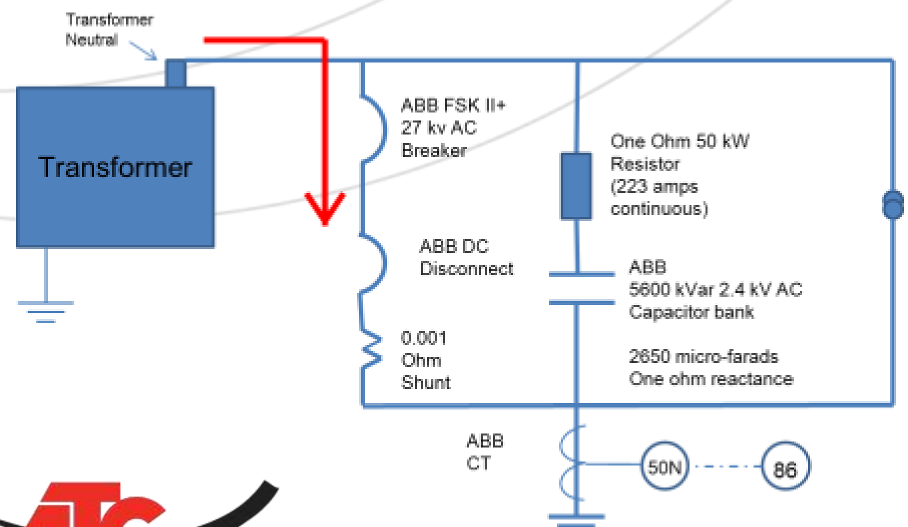
Mitigation—Transformer Neutral Blocking Device

ATC is purchasing and installing one neutral blocking device in 2013

Proof of Concept

- Assess impact of device

  Assess efficacy of device



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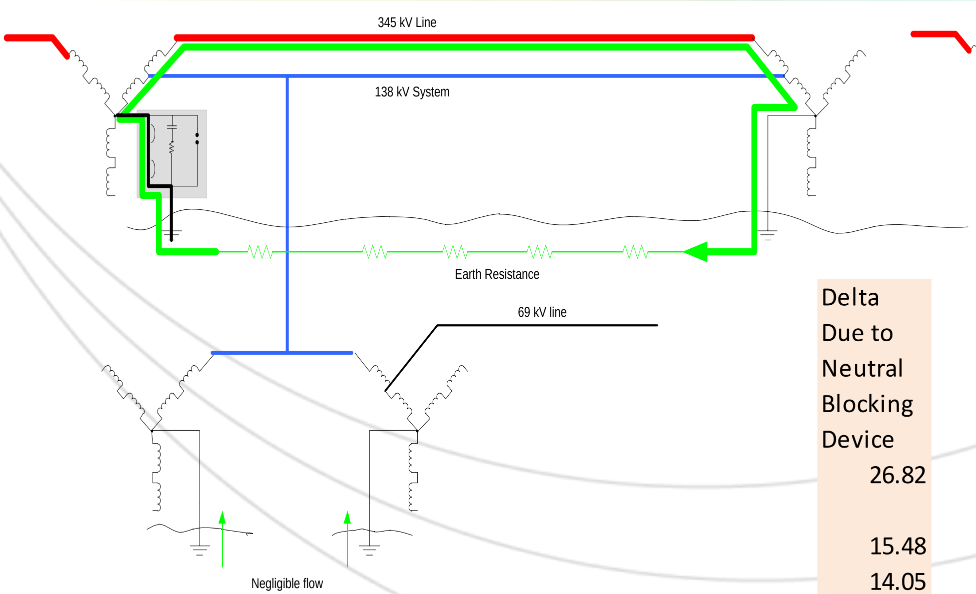
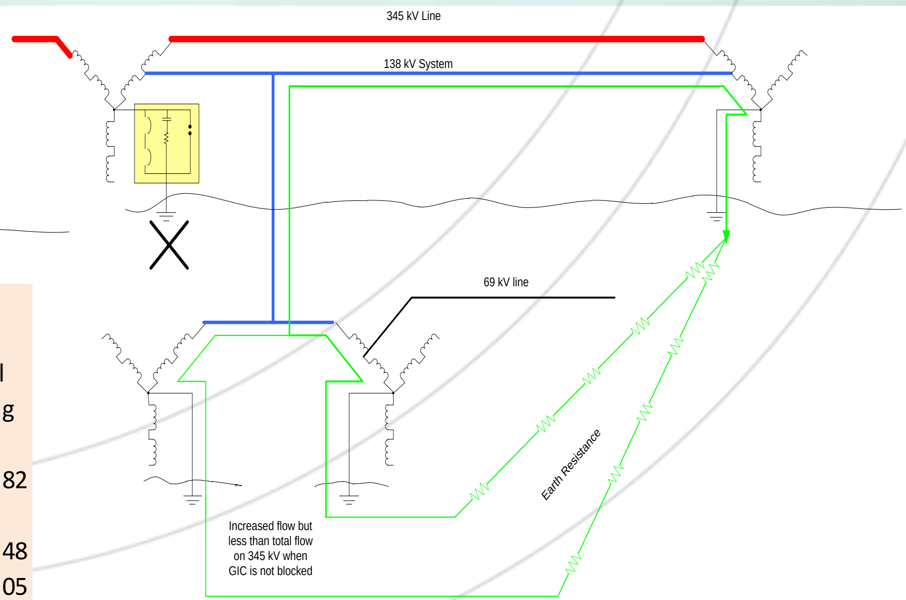
Blocking Consideration—Series Winding Through Flow



Without Neutral Blocking

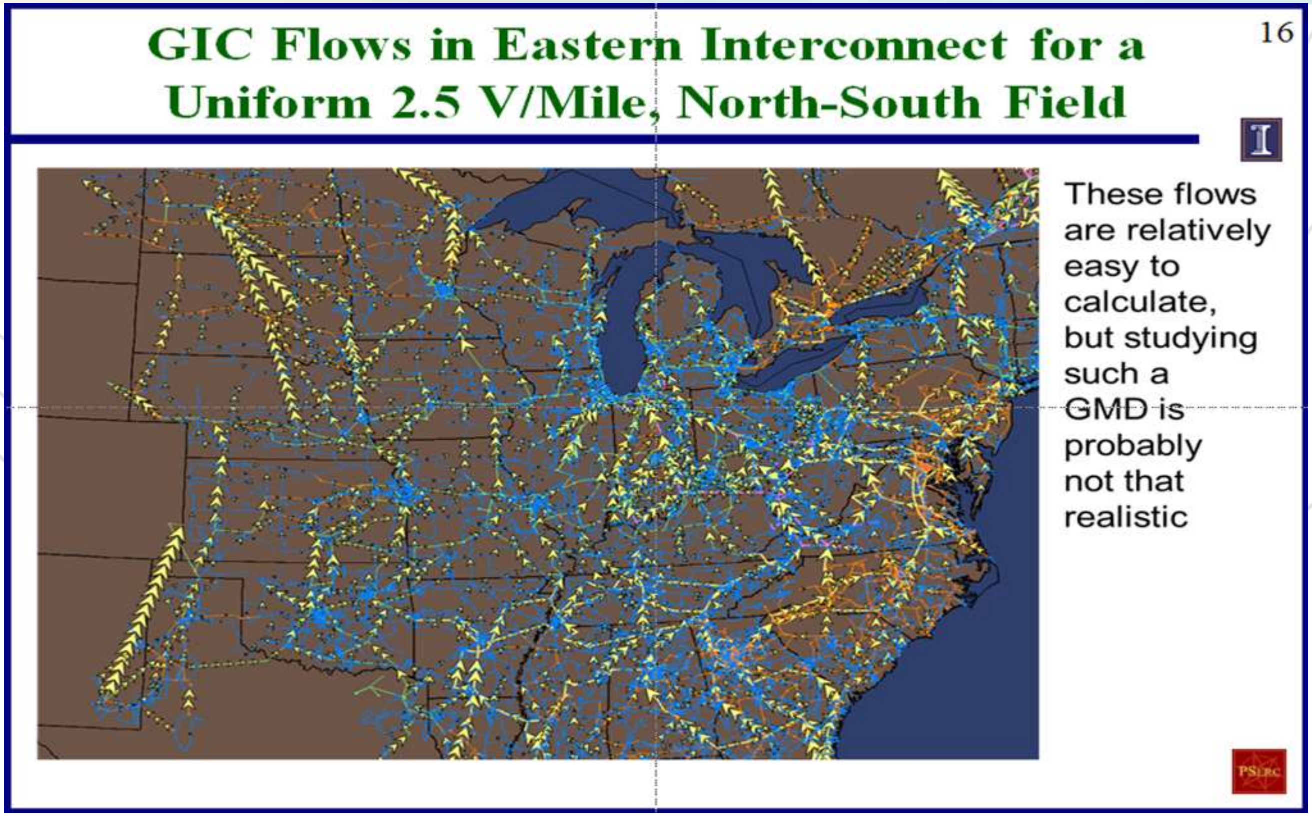
Delta Due to Neutral Blocking Device
26.82
15.48
14.05
0.13
0.11
0.11
0.06
0.06
0.05
0.05
0.04
0.02
0.01

Lower voltage transformers in red



With Neutral Blocking

Modeling GIC



- Latitude and ground resistivity are critical in the actual GIC current
- Latitude and Northern WI/UP high resistivity rock are only a rough estimate in the model

Modeling—Power World GIC Study

Summary GIC table for ATC auto-transformers and member GSUs

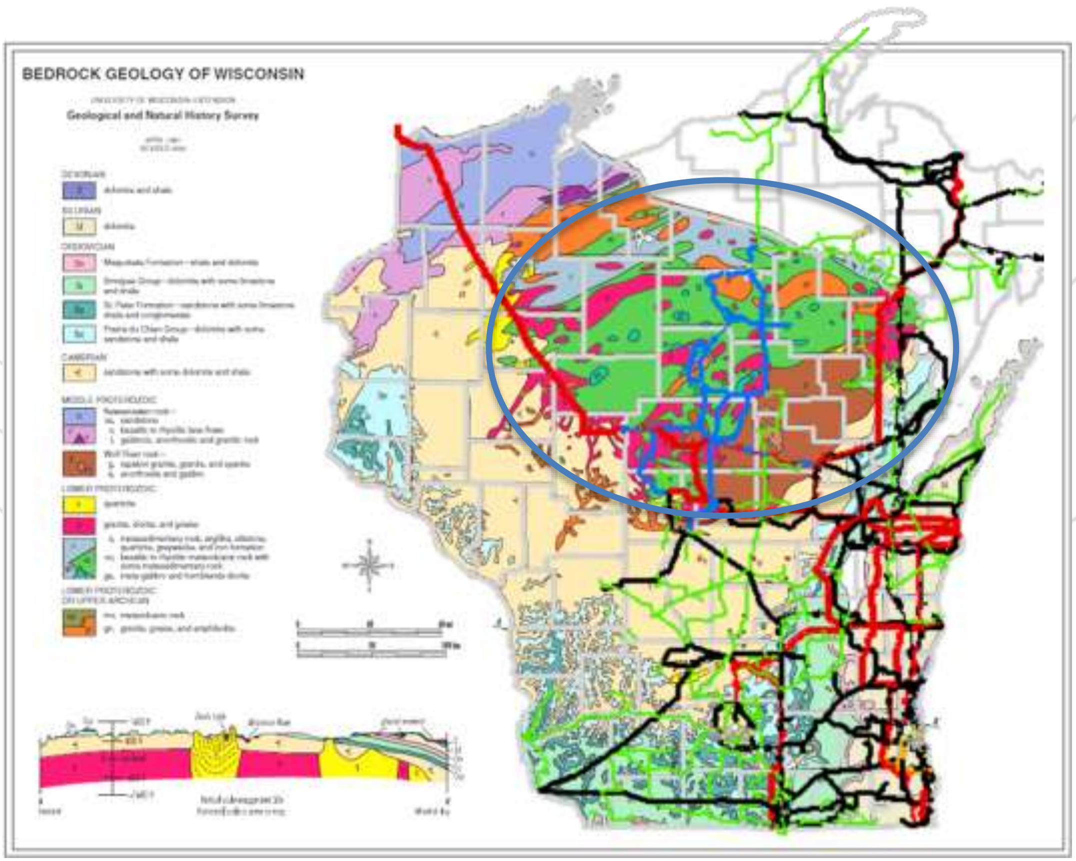
	480 nt/sec storm 2V/km North 1V/Km South		2400 nt/sec storm 10V/km North 6V/Km South		4800 nt/sec storm 20V/km North 12V/Km South	
345kv Auto-Transformers	N-S field	E-W field	N-S field	E-W field	N-S field	E-W field
Arcadian 345/138 #1	-0.7	-12.8	-3.3	-64.2	-6.5	-128.4
Arpin 345/138 #1	3.0	-4.2	15.0	-20.8	30.1	-41.6
Arrowhead 230/230 #1	30.9	-7.6	154.3	-38.1	308.7	-76.2
Arrowhead 345/230 #1	31.9	-25.5	159.6	-127.5	319.1	-255.1
Bain 345/138 #4	-2.2	3.1	-10.9	15.4	-21.9	30.7
Bain 345/138 #5	0.0	2.9	-0.1	14.3	-0.2	28.7
Columbia 345/138 #1	3.0	2.6	15.2	12.8	30.4	25.5
Columbia 345/138 #2	9.2	7.7	46.2	38.7	92.3	77.5
Columbia 345/138 #3	3.1	2.6	15.4	12.9	30.7	25.8
Dead River 345/138 #1	8.2	4.6	41.2	23.2	82.3	46.5
Dead River 345/138 #1A	9.8	5.5	48.9	27.6	97.9	55.3
Edgewater 345/138 #1	-0.2	23.3	-1.0	116.6	-2.0	233.3
Edgewater 345/138 #2	-0.2	21.8	-0.9	108.8	-1.8	217.5
Fitzgerald 345/138 #1	-5.0	-23.5	-25.0	-117.7	-50.0	-235.4
Forest Junction 345/138 #2	12.8	1.4	64.2	7.1	128.3	14.1
Gardner Park 345/115 #1	-3.2	5.0	-16.2	25.1	-32.4	50.1
Gardner Park 345/115 #2	-3.2	5.0	-16.2	25.1	-32.5	50.3
Granville 345/138 #1	-18.5	1.8	-92.5	9.2	-184.9	18.4
Granville 345/138 #1	6.0	2.2	29.8	11.2	59.5	22.5
Kewaunee 345/138 #1	0.0	3.0	0.0	14.8	0.1	29.7
Kewaunee 345/138 #2	0.0	8.3	0.1	41.7	0.2	83.4
Morgan 345/138 # 1	-10.6	12.4	-53.0	61.9	-105.9	123.8
N. Appleton 345/138 #2	5.1	-1.9	25.5	-9.3	51.0	-18.7
N. Appleton 345/138 #3	6.3	-5.8	31.7	-29.2	63.3	-58.4
N. Appleton 345/138 #1	9.4	-0.5	46.8	-2.7	93.6	-5.4
N. Madison 345/138 #1	-3.4	-5.1	-17.2	-25.4	-34.3	-50.8
N. Madison 345/138 #2	-3.4	-5.1	-17.2	-25.5	-34.5	-51.0
Oak Creek North 345/138 #1	-9.7	22.9	-48.6	114.7	-97.3	229.3
Oak Creek North 345/138 #2	-10.8	25.4	-53.8	126.9	-107.7	253.8
Oak Creek North 345/230 #2	-1.5	1.9	-7.4	9.7	-14.7	19.5
Oak Creek North 345/230 #1	-1.1	1.5	-5.7	7.4	-11.3	14.8
Paddock 345/138 #1	-4.6	-13.4	-22.9	-66.8	-45.8	-133.7
Plains 345/138 #1	14.5	-1.4	72.5	-6.9	145.0	-13.9
Racine 345/138 #1	-4.2	3.7	-21.2	18.7	-42.3	37.4
Racine 345/138 #2	-15.9	4.7	-79.5	23.7	-159.1	47.4
Rockdale 345/138 #1	1.7	2.3	8.4	11.3	16.7	22.6
Rockdale 345/138 #2	7.4	10.0	36.9	49.8	73.7	99.6
Rockdale 345/138 #3	5.1	6.8	25.3	34.2	50.6	68.4
Rocky Run 345/115 #1	-1.2	-0.8	-5.9	-4.2	-11.9	-8.4
Rocky Run 345/115 #2	-2.7	-1.9	-13.4	-9.6	-26.9	-19.1
Rocky Run 345/115 #3	-1.7	-1.2	-8.4	-6.0	-16.8	-11.9
Saukville 345/138 #1	17.0	29.6	85.0	148.2	170.0	296.4
South Fond Du Lac 345/138 #1	0.2	0.8	1.2	3.8	2.3	7.6
South Fond Du Lac 345/138 #2	0.2	0.7	1.1	3.7	2.3	7.4
Stone Lake 345/161 #1	-50.7	-22.8	-253.4	-114.0	-506.9	-228.1
W. Middleton/Cardinal 345/138 #1	7.9	-36.2	39.6	-181.0	79.3	-361.9
Werner West 345/138 #1	-28.1	-26.8	-140.7	-134.0	-281.5	-267.9

	480 nt/sec storm 2V/km North 1V/Km South		2400 nt/sec storm 10V/km North 6V/Km South		4800 nt/sec storm 20V/km North 12V/Km South	
345kv GSU's	N-S field	E-W field	N-S field	E-W field	E-W field	N-S field
Columbia (WPL) 345/22 #1	49.1	-30.4	245.3	-152.0	490.6	-304.0
Columbia (WPL) 345/22 #1	49.5	-30.7	247.7	-153.5	495.4	-306.9
Cypress 345/35 #1	-19.9	-7.1	-99.5	-35.5	-198.9	-71.0
Edgewater (WPL) 345/22 #1	11.3	18.3	56.4	91.5	112.8	183.1
Edgewater (WPL) 345/22 #1	19.4	31.5	97.1	157.6	194.2	315.3
Gardner Park 345/19 #1	10.2	-20.7	50.9	-103.3	101.9	-206.7
Kewaunee 345/20 #1	19.0	30.8	95.1	154.0	190.2	308.0
Oak Creek North 345/25 #1	6.1	9.8	30.4	48.9	60.8	97.8
Oak Creek North 345/25 #1	6.3	10.2	31.6	50.9	63.2	101.8
Pleasant Prairie 345/24 #1	-12.2	4.2	-60.9	21.1	-121.8	42.2
Pleasant Prairie 345/24 #1	-12.1	4.2	-60.7	21.0	-121.3	42.0
Point Beach 345/19 #1	12.8	36.2	64.1	181.1	128.2	362.2
Point Beach 345/19 #1	14.5	36.4	72.7	182.2	145.4	364.3
SEC 345/18 #1	-19.0	0.3	-94.8	1.7	-189.5	3.3
SEC 345/18 #1	-18.8	0.3	-94.0	1.7	-188.0	3.3

GSU's are more susceptible to GIC

1. Transformer are fully loaded – heating damage could occur
2. Lower impedance for GIC currents
3. System Models need further refinement to account for soil differences in WI

Modeling—Soil Conductivity Discontinuities



Mitigation--ATC's World View

We are a "Transmission Only" utility

- Modeling must be a cooperative regional effort
  - Account for neighbors system
  - Coordinate responses with neighbors
  - Similar to NERC ERAG MMWG

- Mitigation must be done cooperatively
  - Impacts on Generators in our system
  - Impacts on other systems
  - Regional approach needed

Conclusions

- We are moving ahead with the 3Ms of GIC
  - Measurement
    - 22 GIC monitors installed and displayed to Operators
    - Add Harmonics capability for 44 transformers in 2013
  - Modeling
  - Mitigation
- We need to continuously implement and learn

Questions

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